COSMOS Annual Meeting

Overview of Ground Motions

ATC-63 Project

“Quantification of Building System and Response Parameters”

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November 17, 2006

ATC -63 Project Objectives

- **Primary** – Create a methodology for determining Seismic Performance Factors (SPF's) "that, when properly implemented in the design process, will result in the equivalent earthquake performance of buildings having different structural systems" (i.e., different lateral-force-resisting systems)
- **Secondary** – Evaluate a sufficient number of different lateral-force-resisting systems to provide a basis for Seismic Code committees (e.g., BSSC PUC) to develop a simpler set of lateral-force-resisting systems and more rational SPF's (and related design criteria) that would more reliably achieve the inherent earthquake safety performance objectives of building codes

Project Organization

FEMA

Applied Technology Council

TOP Management Committee
Project Executive Director (Chair)
Project Technical Monitor
Project Quality Control Monitor

ATC-63 Project Management Committee
Project Technical Director (Chair)
Five Members

Project Review Panel
Twelve Members

Working Groups
Technical Consultants

ATC Staff
Technical Support
Administration

PMC Members

Kircher (Chair)
Deierlein – Stanford
Constantinou – Buffalo
Hooper - MKA
Harris – HA
Porush - URS

PRP Members

Phipps (Chair)
Elnashai - MAE
Ghosh - SKGA
Gilsanz- GMS
Hamburger - SGH
Hayes - NIST
Holmes – R&C
Klingner - UT
Line - AFPA
Manley - AISI
Reinhorn - UB
Rojahn - ATC
Sabelli - DASSE

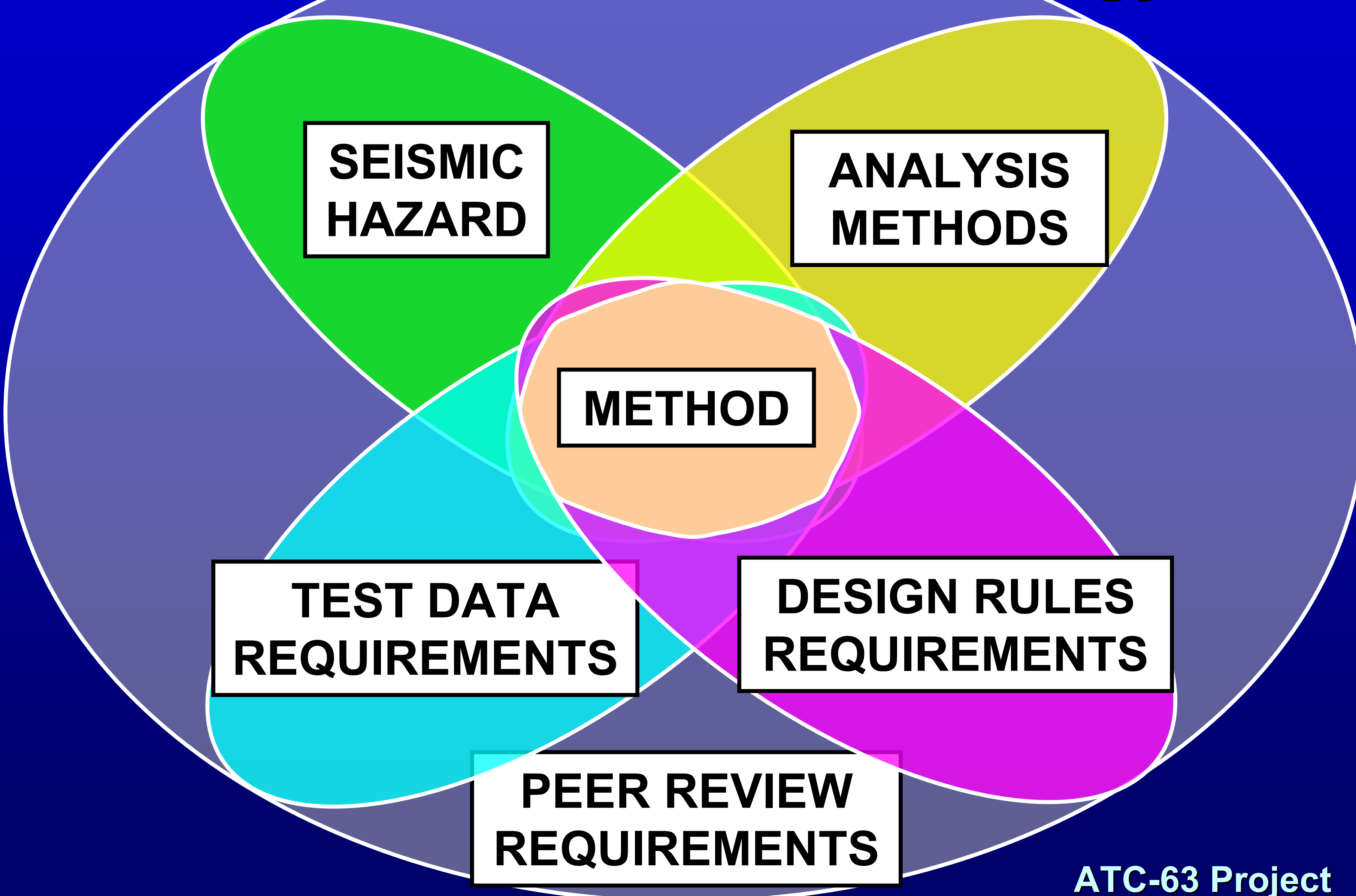
Working Groups

Stanford – NDA
SUNY – NSA/NCA
Filiatrault – Wood
Krawinkler - AAC

Guiding Principals

- New Buildings – Methodology will apply to the lateral-force-resisting system of new buildings and may not be appropriate for non-building structures and will not apply to nonstructural systems.
- *NEHRP Provisions* – Methodology will be based on design criteria, detailing requirements, etc. of the *NEHRP Provisions* (i.e., *ASCE 7-05* as adopted by the BSSC for future *NEHRP Provisions* development)
- Life Safety – Methodology will be based on life safety performance (only) and will not address damage protection and functionality issues (e.g., I = 1.0 will be assumed)
- Structure Collapse – Life safety performance will be achieved by providing uniform protection against local or global collapse of the lateral-force-resisting system for MCE ground motions
- Ground Motions – MCE ground motions will be based on the spectral response parameters of the *NEHRP Provisions*, including site class effects

Elements of the Methodology



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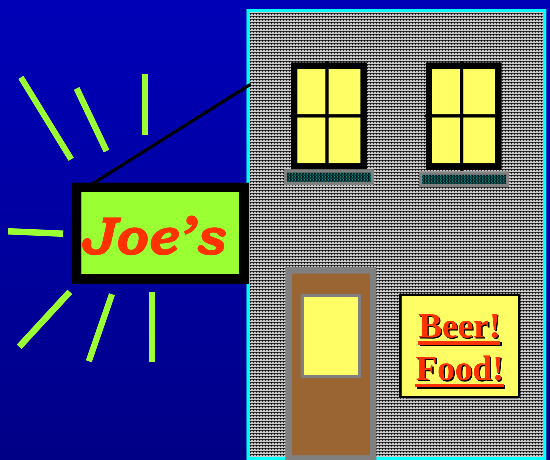
Methodology Overview

- Conceptual Framework – Methodology will be based on the same concepts as those found in the Commentary of *FEMA 450* (*ASCE 7-05*) to describe SPF's (i.e., global pushover curve concept)
- Failure Modes – Methodology will evaluate structural collapse defined by system-dependent local and global modes of failure
- **Collapse Probability** – Methodology will determine structural collapse probability considering response and capacity variability (and epistemic and aleatory uncertainty)
- Archetypical Systems – Methodology will define and be based on "archetypical" structural systems that have configurations that are typical of a given type or class of lateral-force-resisting system
- Analytical Models – Methodology will be based on models (of archetypical systems) that have sufficient complexity to realistically represent global performance of actual building systems considering nonlinear inelastic behavior of seismic-force-resisting components
- Analytical Methods – Methodology will be based on nonlinear analysis methods (both NDA and NSA will be investigated)

Example Collapse Fragility – One Data Point

Building (Joe's Bar)



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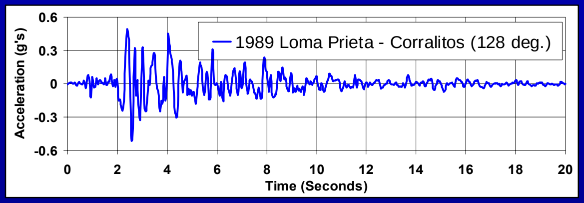
Scaled Ground Motion Record



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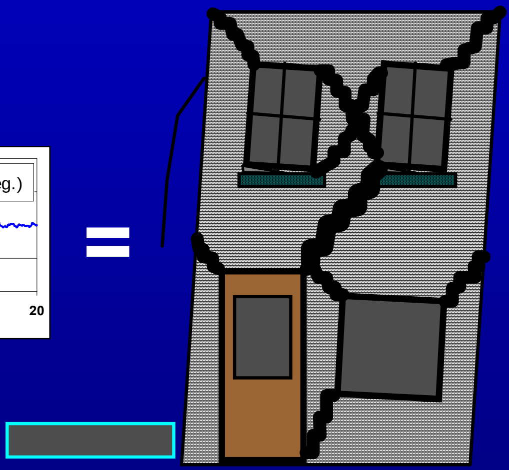
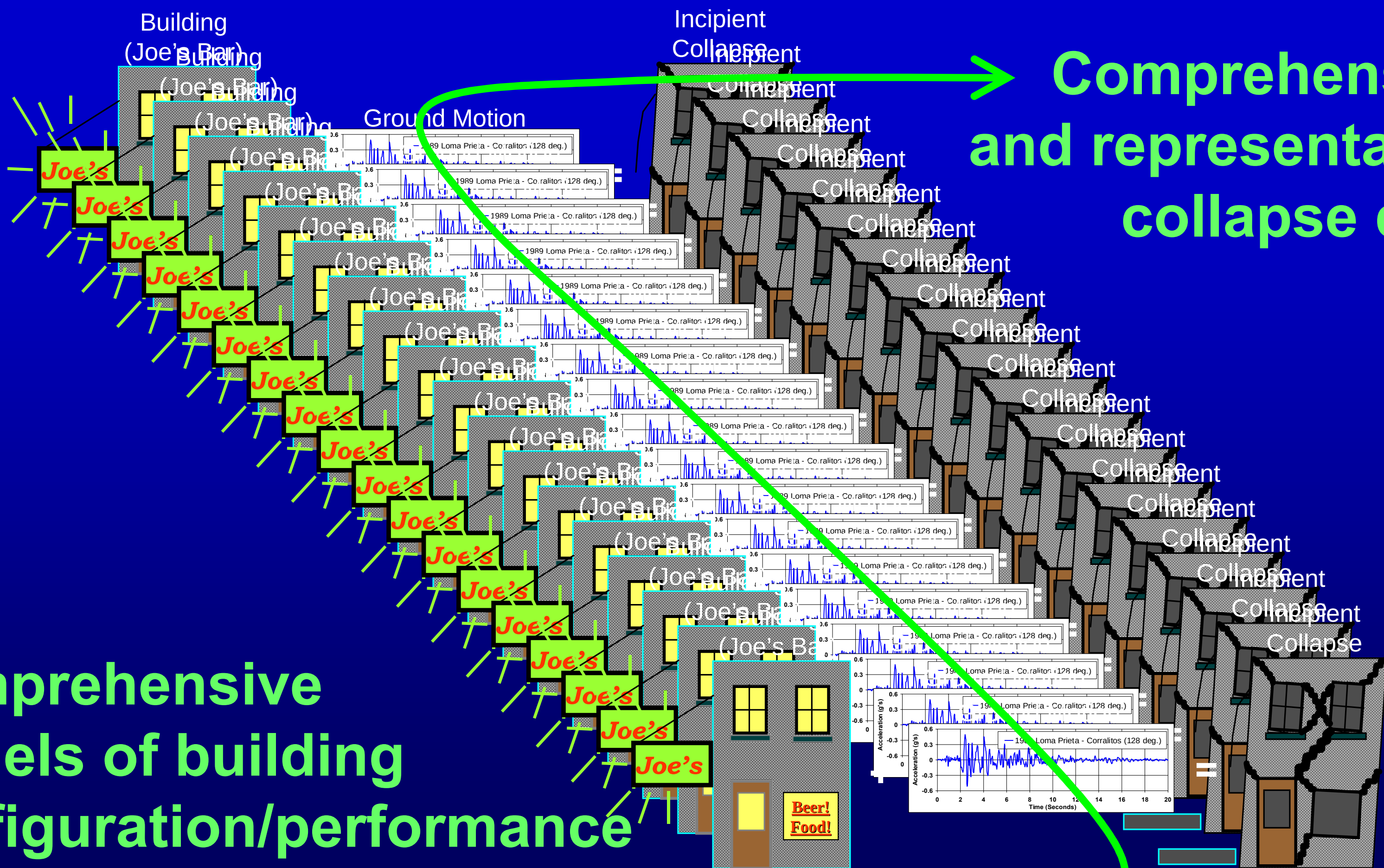
Incipient Collapse



Evaluation of a single structure (one configuration/set of performance properties) to failure using one ground motion record scaled to effect incipient collapse

Example Collapse Fragility – Comprehensive and Representative Collapse Data



Comprehensive and representative collapse data

Comprehensive models of building configuration/performance properties evaluated with representative earthquake records

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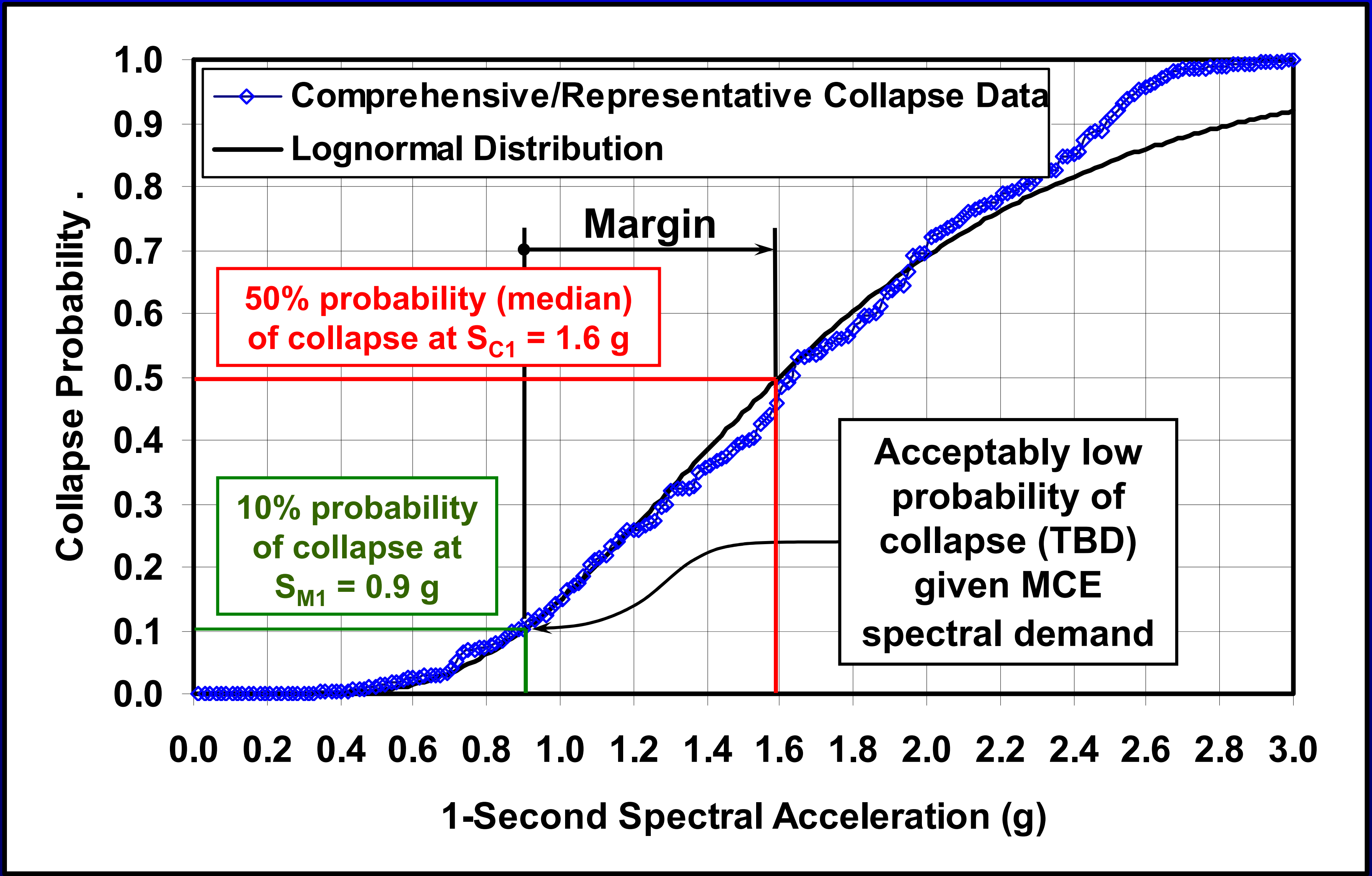
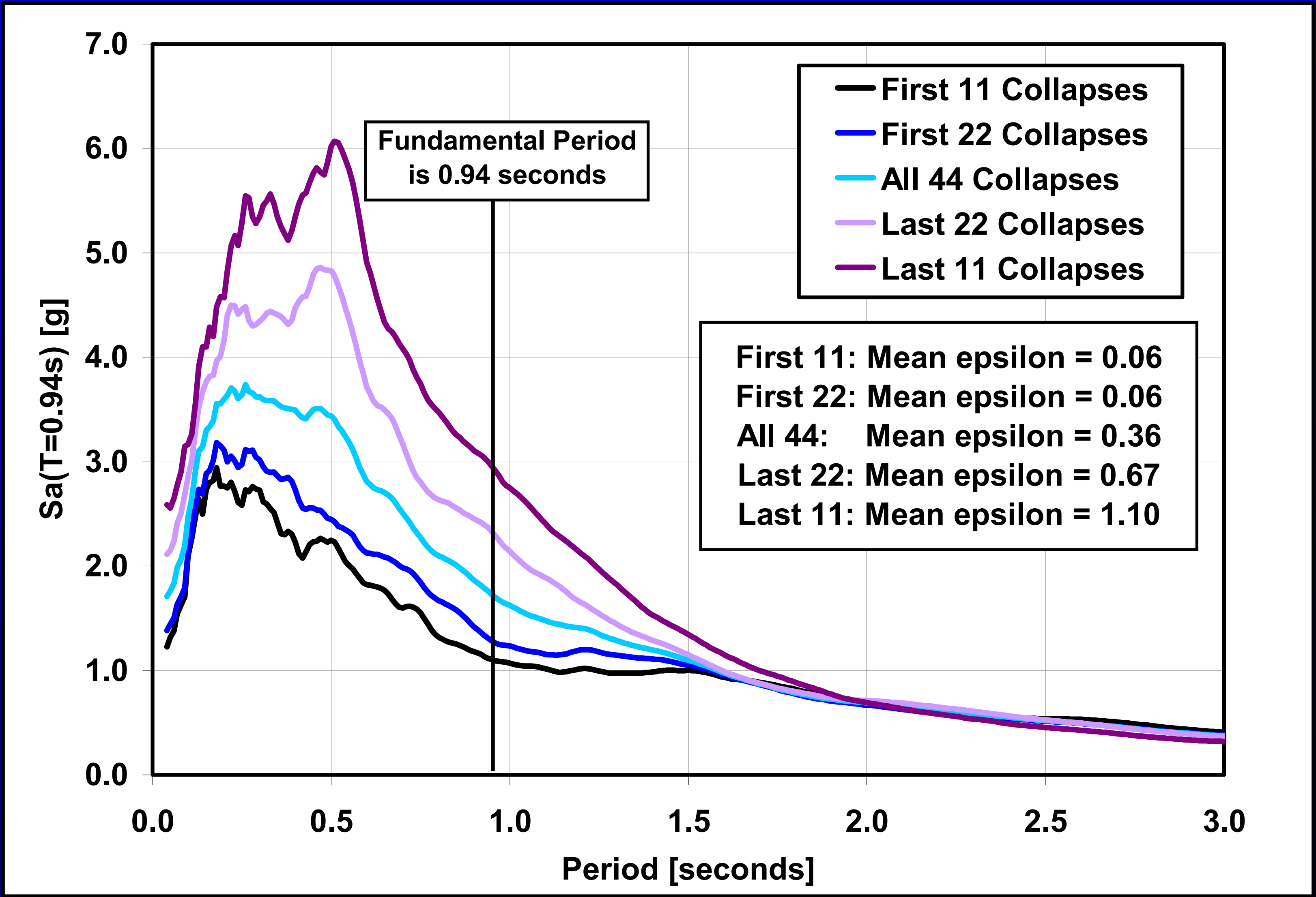
Notional Collapse Fragility Curve



ATC-63 Ground Motion Record Sets - Objectives

- **Code (*ASCE 7-05*) Consistent** – Pairs of horizontal components "selected and scaled from individual recorded events." Section 16.1.3.1 of *ASCE 7-05*
- **Very Strong Ground motions** – Ground motions strong enough to collapse new buildings
- **Large Number of Records** – Enough records in set to estimate median and RTR variability (collapse fragility)
- **Structure-Type Independent** – Appropriate for NDA (IDA) of variety structures with different dynamic characteristics and performance properties
- **Site/Hazard Independent** – Appropriate for evaluation of structures located at different sites/hazard levels

Example Comparison of Median Response Spectra at Collapse – 4-Story R/C SMF Archetype Building



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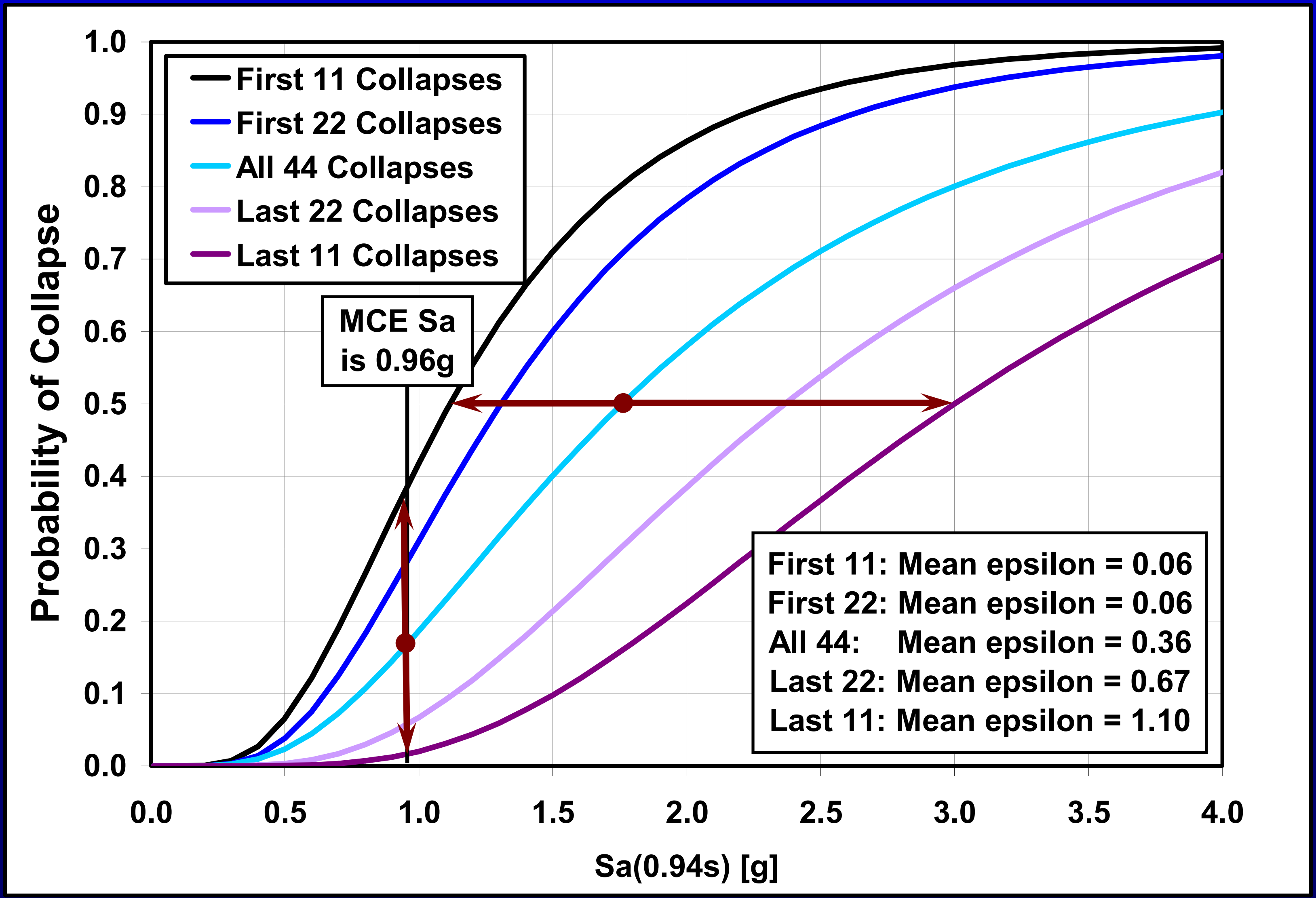
Example Comparison of Collapse Fragility Curves – 4-Story R/C SMF Model Building



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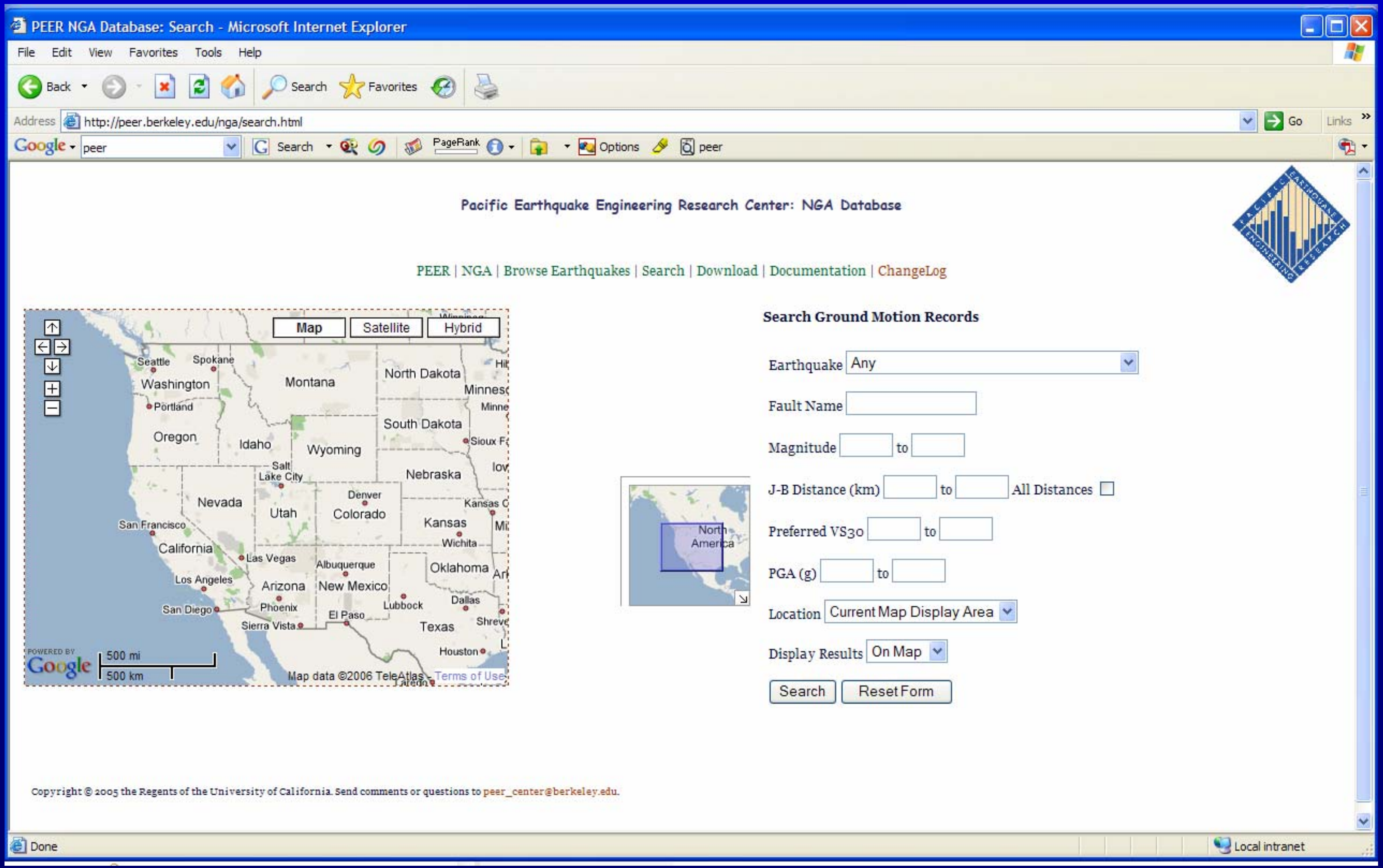
Record Source - PEER-NGA Database

- 3,551 records (http://peer.berkeley.edu/nga/)



Record Selection Criteria

- **Source Magnitude** – Large magnitude, M ≥ 6.5, events
- **Source Type** – Strike-slip and Reverse (Thrust) sources
- **Site Conditions** – Rock or Stiff Soil Sites, Vs > 180 m/s
- **Site-Source Distance** - Far-Field Set, R > 10 km
  Near-Field Set, R ≤ 10km
- **Number of Records per Event** – Not more than 2 records
- **Strongest Records** - PGA > 0.2g and PGV > 15 cm/sec
- **Strong-Motion Instrumentation:**
  - Valid frequency content to at least 4-second period
  - Free-field (or ground floor of small building)

Ground Motion Record Sets

- **Far-field Record Set (Basic Set):**
  - 22 records (2 components each)
  - 14 Events
  - Mechanisms: 9 strike-slip, 5 thrust
- **Near-field Record Set:**
  - 28 records (2 components each)
  - 14 Events
  - Half of records with a pulse, half without a pulse
- **Scale records (consistent with *ASCE 7-05*):**
  - Normalize individual records by PGV
  - Anchor record set median spectral demand to MCE demand (at period of structure)

ID No.	Earthquake			Recording Station	
	Mag.	Year	Name	Name	Owner
1	6.7	1994	Northridge	Beverly Hills - 14145 Mulhol	USC
2	6.7	1994	Northridge	Canyon Country-W Lost Cany	USC
3	7.1	1999	Duzce, Turkey	Bolu	ERD
4	7.1	1999	Hector Mine	Hector	SCSN
5	6.5	1979	Imperial Valley	Delta	UNAMUCSD
6	6.5	1979	Imperial Valley	El Centro Array #11	USGS
7	6.9	1995	Kobe, Japan	Nishi-Akashi	CUE
8	6.9	1995	Kobe, Japan	Shin-Osaka	CUE
9	7.5	1999	Kocaeli, Turkey	Duzce	ERD
10	7.5	1999	Kocaeli, Turkey	Arcelik	KOERI
11	7.3	1992	Landers	Yermo Fire Station	CDMG
12	7.3	1992	Landers	Coolwater	SCE
13	6.9	1989	Loma Prieta	Capitola	CDMG
14	6.9	1989	Loma Prieta	Gilroy Array #3	CDMG
15	7.4	1990	Manjil, Iran	Abbar	BHRC
16	6.5	1987	Superstition Hills	El Centro Imp. Co. Cent	CDMG
17	6.5	1987	Superstition Hills	Poe Road (temp)	USGS
18	7.0	1992	Cape Mendocino	Rio Dell Overpass - FF	CDMG
19	7.6	1999	Chi-Chi, Taiwan	CHY101	CWB
20	7.6	1999	Chi-Chi, Taiwan	TCU045	CWB
21	6.6	1971	San Fernando	LA - Hollywood Stor FF	CDMG
22	6.5	1976	Friuli, Italy	Tolmezzo	--

Far-Field Set (Events)

- 14 Events
- 22 Records

  44 Comp's
- Magnitudes:

  Avg - M7.0

  Max – M7.6

  Min – M6.5

ID No.	Site Data		Source (Fault Type)	Site-Source Distance (km)			
	NEHRP Class	Vs_30 (m/sec)		Epicentral	Campbell	Closest	Joyner-Boore
1	D	356	Thrust	13.3	17.2	17.2	9.4
2	D	309	Thrust	26.5	12.4	12.4	11.4
3	D	326	Strike-slip	41.3	12.4	12	12
4	C	685	Strike-slip	26.5	12	11.7	10.4
5	D	275	Strike-slip	33.7	22.5	22	22
6	D	196	Strike-slip	29.4	13.5	12.5	12.5
7	C	609	Strike-slip	8.7	25.2	7.1	7.1
8	D	256	Strike-slip	46	28.5	19.2	19.1
9	D	276	Strike-slip	98.2	15.4	15.4	13.6
10	C	523	Strike-slip	53.7	13.5	13.5	10.6
11	D	354	Strike-slip	86	23.8	23.6	23.6
12	D	271	Strike-slip	82.1	20	19.7	19.7
13	D	289	Strike-slip	9.8	35.5	15.2	8.7
14	D	350	Strike-slip	31.4	12.8	12.8	12.2
15	C	724	Strike-slip	40.4	13	12.6	12.6
16	D	192	Strike-slip	35.8	18.5	18.2	18.2
17	D	208	Strike-slip	11.2	11.7	11.2	11.2
18	D	312	Thrust	22.7	14.3	14.3	7.9
19	D	259	Thrust	32	15.5	10	10
20	C	705	Thrust	77.5	26.8	26	26
21	D	316	Thrust	39.5	25.9	22.8	22.8
22	C	425	Thrust	20.2	15.8	15.8	15

Far-Field Set (Site/Sources)

- Site Classes:
  - C – 6 rec's
  - D – 16 rec's
- Source Types:
  - Strike – 15 rec's
  - Thrust – 7 rec's
- Distance:
  - Avg – 16.4 km
  - Max – 26.4 km
  - Min – 11.1 km

ID No.	PEER-NGA Record Information				Recorded Motions	
	Record Seq. No.	Lowest Freq (Hz.)	File Names - Horizontal Records		PGA_{max} (g)	PGV_{max} (cm/sec.)
			Component 1	Component 2		
1	953	0.25	NORTHR/MUL009.at2	NORTHR/MUL279.at2	0.52	63
2	960	0.13	NORTHR/LOS000.at2	NORTHR/LOS270.at2	0.48	45
3	1602	0.06	DUZCE/BOL000.at2	DUZCE/BOL090.at2	0.82	62
4	1787	0.04	HECTOR/HEC000.at2	HECTOR/HEC090.at2	0.34	42
5	169	0.06	IMPVALL/H-DLT262.at2	IMPVALL/H-DLT352.at2	0.35	33
6	174	0.25	IMPVALL/H-E11140.at2	IMPVALL/H-E11230.at2	0.38	42
7	1111	0.13	KOBE/NIS000.at2	KOBE/NIS090.at2	0.51	37
8	1116	0.13	KOBE/SHI000.at2	KOBE/SHI090.at2	0.24	38
9	1158	0.24	KOCAELI/DZC180.at2	KOCAELI/DZC270.at2	0.36	59
10	1148	0.09	KOCAELI/ARC000.at2	KOCAELI/ARC090.at2	0.22	40
11	900	0.07	LANDERS/YER270.at2	LANDERS/YER360.at2	0.24	52
12	848	0.13	LANDERS/CLW-LN.at2	LANDERS/CLW-TR.at2	0.42	42
13	752	0.13	LOMAP/CAP000.at2	LOMAP/CAP090.at2	0.53	35
14	767	0.13	LOMAP/G03000.at2	LOMAP/G03090.at2	0.56	45
15	1633	0.13	MANJIL/ABBAR--L.at2	MANJIL/ABBAR--T.at2	0.51	54
16	721	0.13	SUPERST/B-ICC000.at2	SUPERST/B-ICC090.at2	0.36	46
17	725	0.25	SUPERST/B-POE270.at2	SUPERST/B-POE360.at2	0.45	36
18	829	0.07	CAPEMEND/RIO270.at2	CAPEMEND/RIO360.at2	0.55	44
19	1244	0.05	CHICHI/CHY101-E.at2	CHICHI/CHY101-N.at2	0.44	115
20	1485	0.05	CHICHI/TCU045-E.at2	CHICHI/TCU045-N.at2	0.51	39
21	68	0.25	SFERN/PEL090.at2	SFERN/PEL180.at2	0.21	19
22	125	0.13	FRIULI/A-TMZ000.at2	FRIULI/A-TMZ270.at2	0.35	31

Far-Field Set (Recorded)

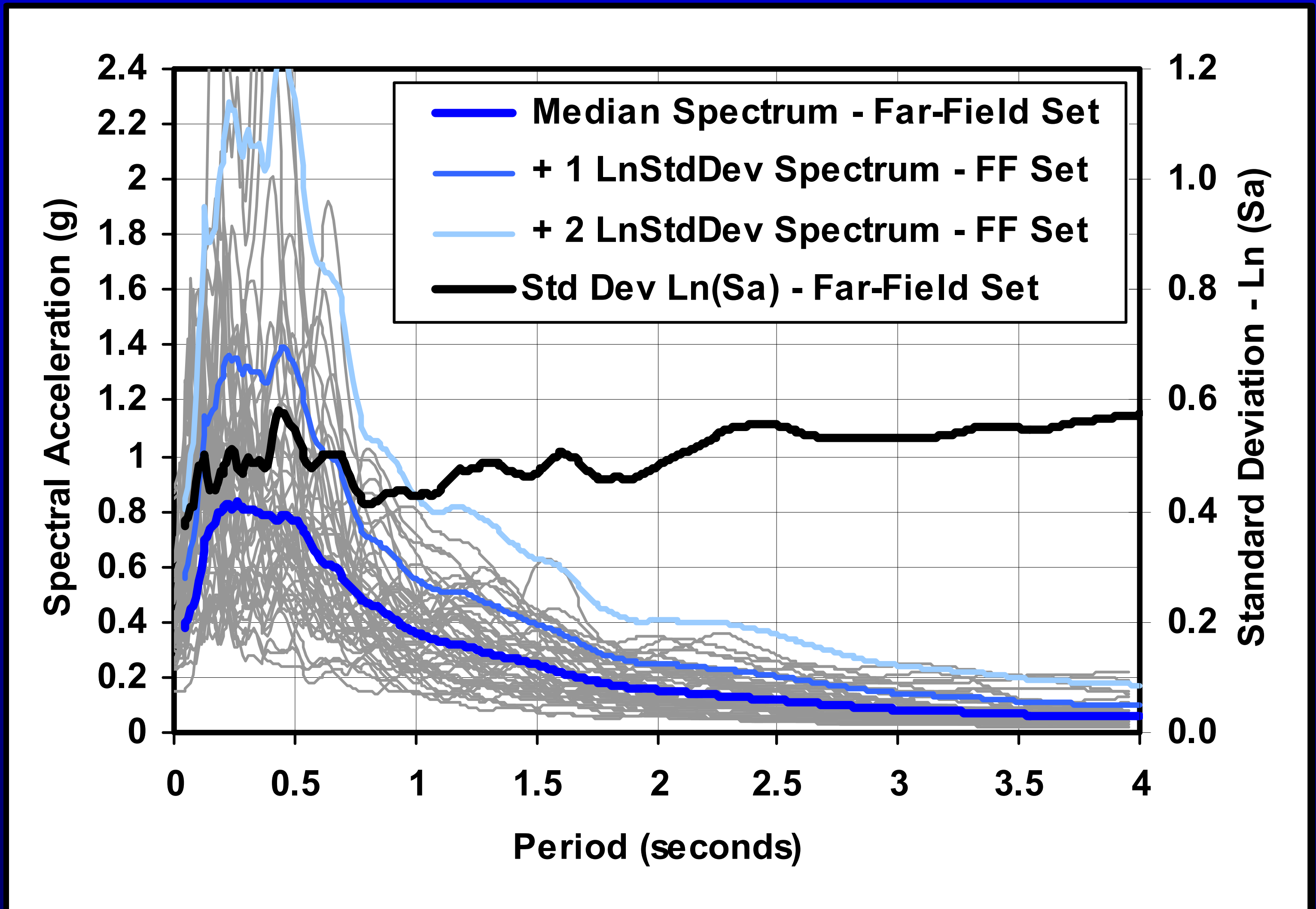
- **Recorded PGA:**
  - Avg – 0.43 g
  - Max – 0.82 g
  - Min – 0.21 g
- **Recorded PGV:**
  - Avg – 46 cm/s
  - Max – 115 cm/s
  - Min – 19 cm/s

ID No.	Normalization Parameters			Normalization Scale Factor	Normalized Motions	
	1-Second Spec. Accel. (g)		PGV_{PEER} (cm/sec.)		PGA_{max} (g)	PGV_{max} (cm/sec.)
	Component 1	Component 2				
1	0.94	1.02	49.3	0.755	0.39	47
2	0.63	0.38	57.2	0.832	0.40	38
3	1.16	0.72	59.2	0.629	0.52	39
4	0.37	0.35	34.1	1.092	0.37	46
5	0.48	0.26	28.4	1.311	0.46	43
6	0.23	0.24	36.7	1.014	0.39	43
7	0.29	0.31	36.1	1.718	0.88	64
8	0.23	0.33	33.9	1.099	0.26	42
9	0.61	0.43	54.1	0.688	0.25	41
10	0.11	0.11	27.4	1.360	0.30	54
11	0.33	0.50	37.7	0.987	0.24	51
12	0.36	0.20	32.4	1.073	0.45	45
13	0.28	0.46	34.2	0.822	0.44	29
14	0.38	0.27	42.3	0.880	0.49	39
15	0.54	0.35	47.3	0.787	0.40	43
16	0.25	0.31	42.8	0.870	0.31	40
17	0.34	0.33	31.7	1.362	0.61	49
18	0.39	0.54	45.4	1.516	0.83	66
19	0.95	0.49	90.7	0.636	0.28	73
20	0.43	0.30	38.8	0.563	0.29	22
21	0.15	0.25	17.8	2.096	0.44	40
22	0.30	0.25	25.9	1.440	0.50	44

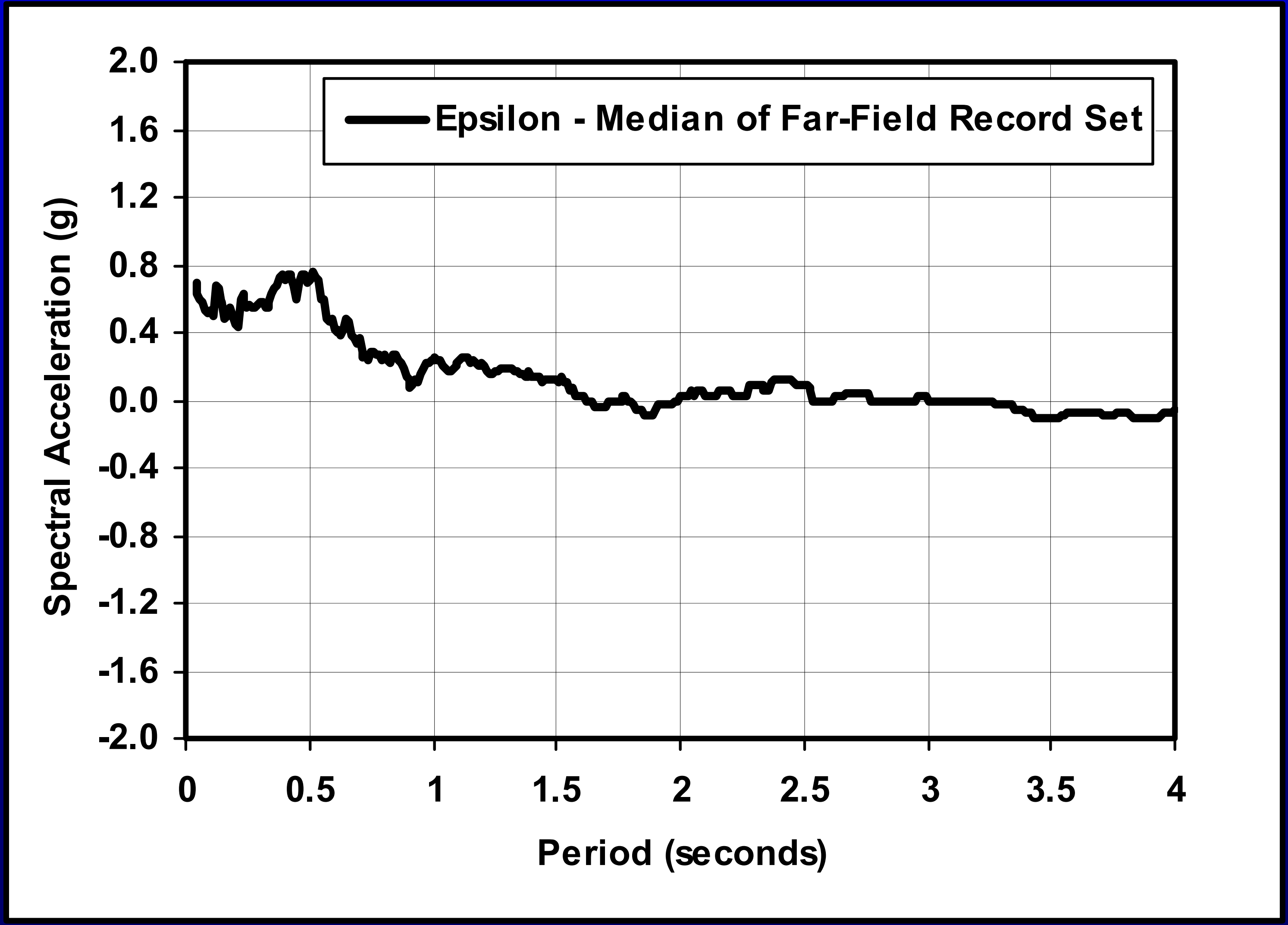
Far-Field Set (Normalized by PGV)

- PGA (Norm.):
  - Avg – 0.43 g
  - Max – 0.88 g
  - Min – 0.24 g
- PGV (Norm.):
  - Avg – 45 cm/s
  - Max – 73 cm/s
  - Min – 22 cm/s

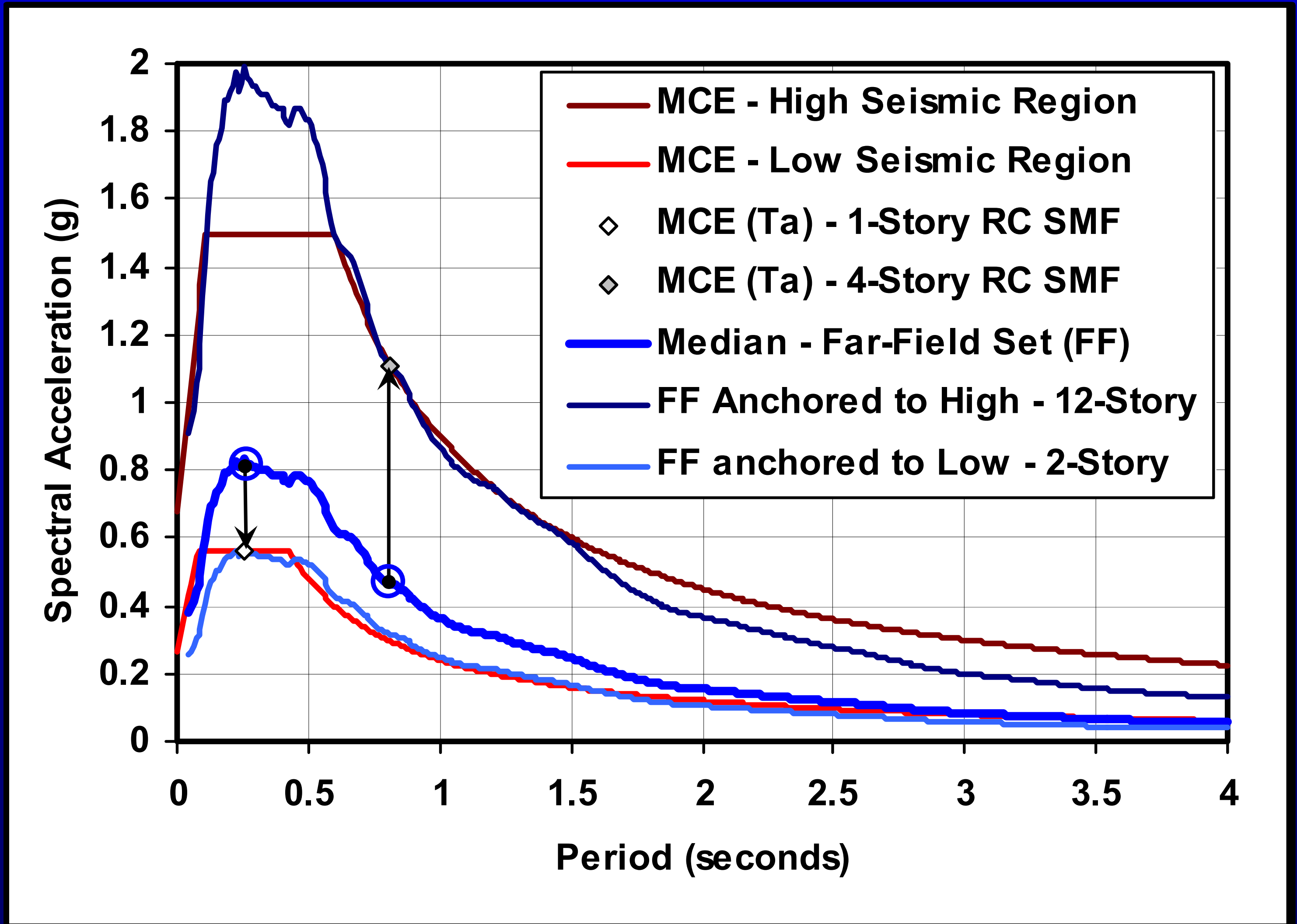
Response Spectra - Far-Field Record Set



Spectral Shape – Far-Field Record Set



Anchoring Median Ground Motions to MCE Demand
(at approximate fundamental period of Structure)



Ground Motion Record Sets

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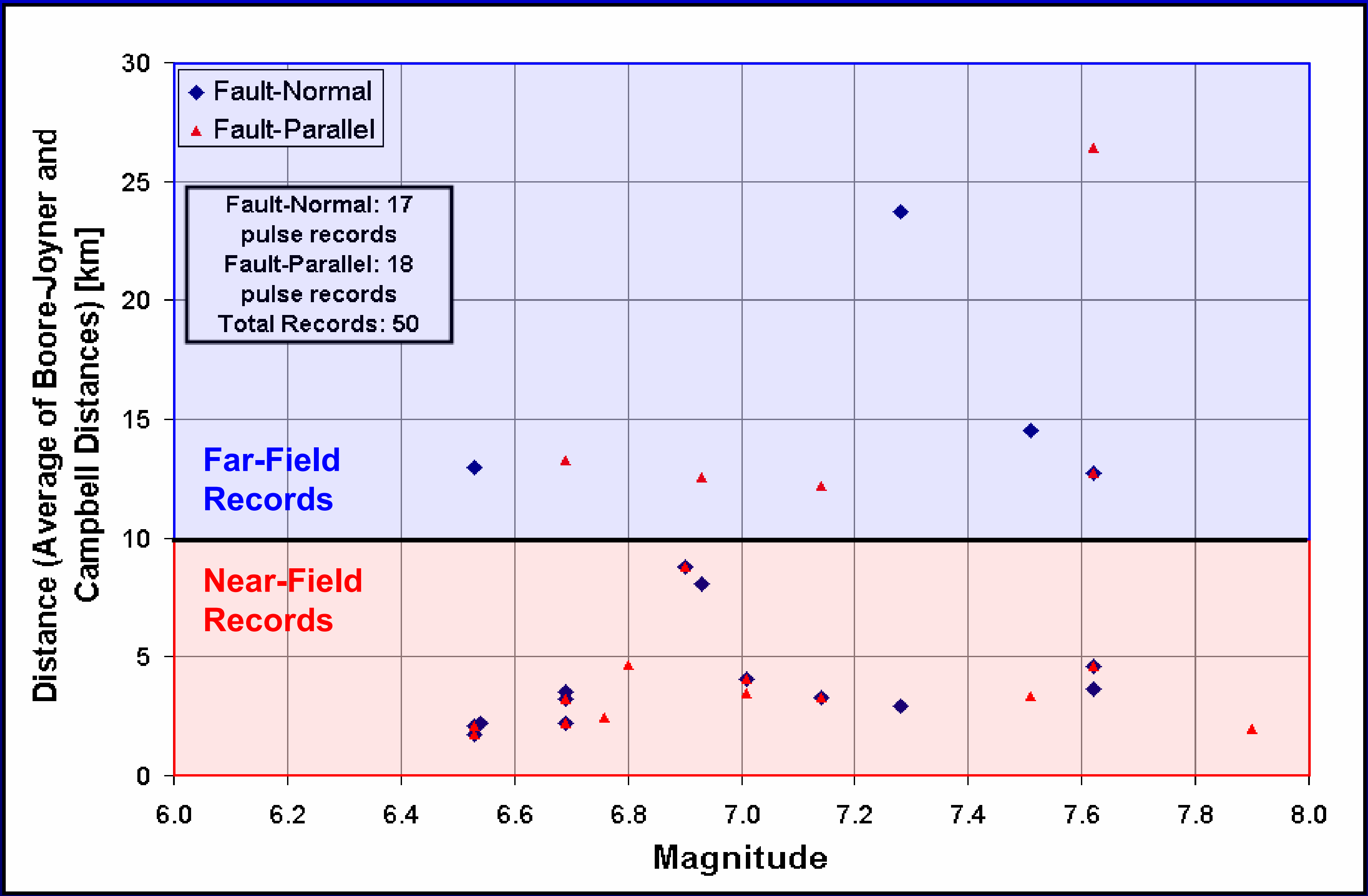
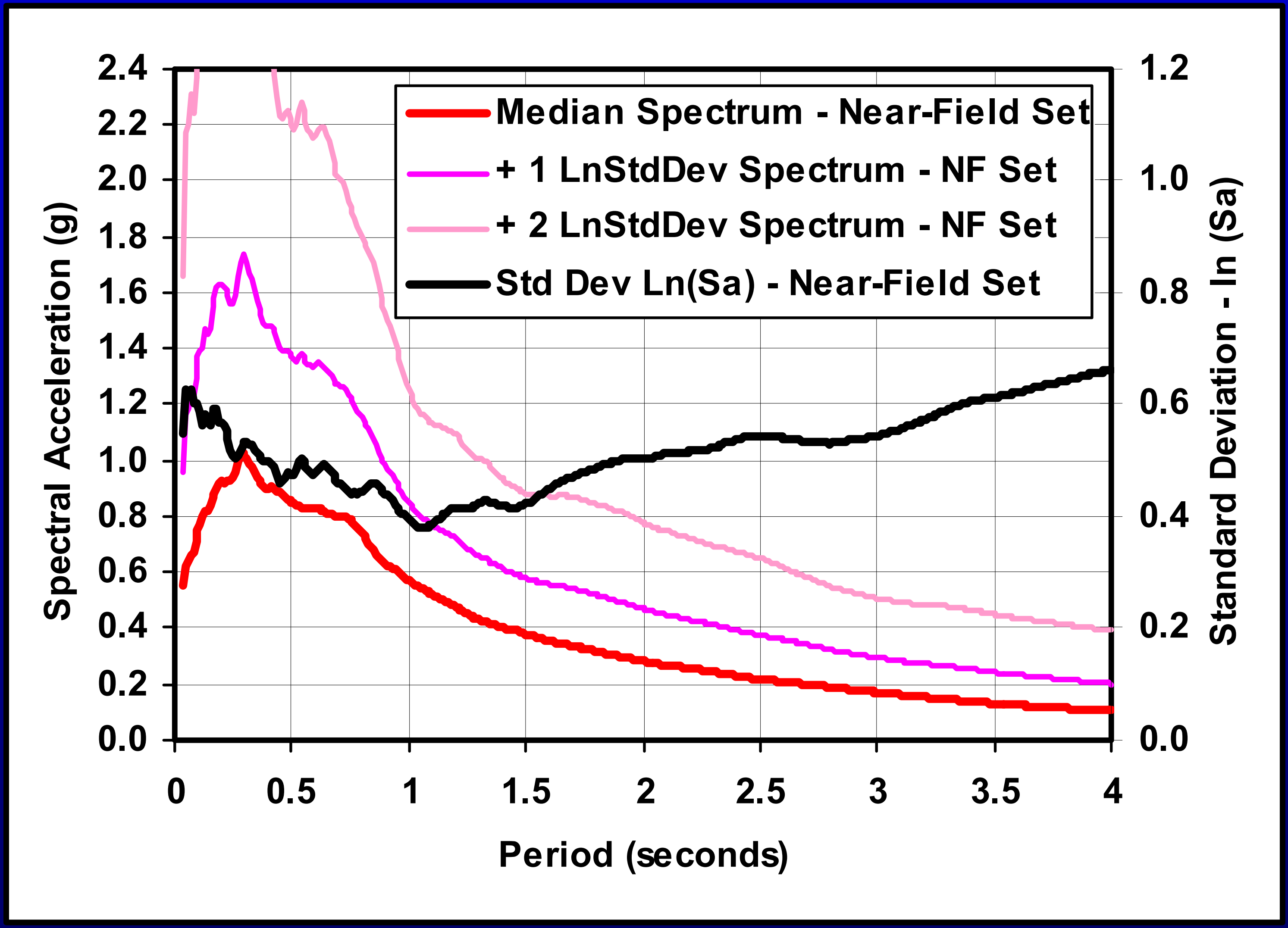
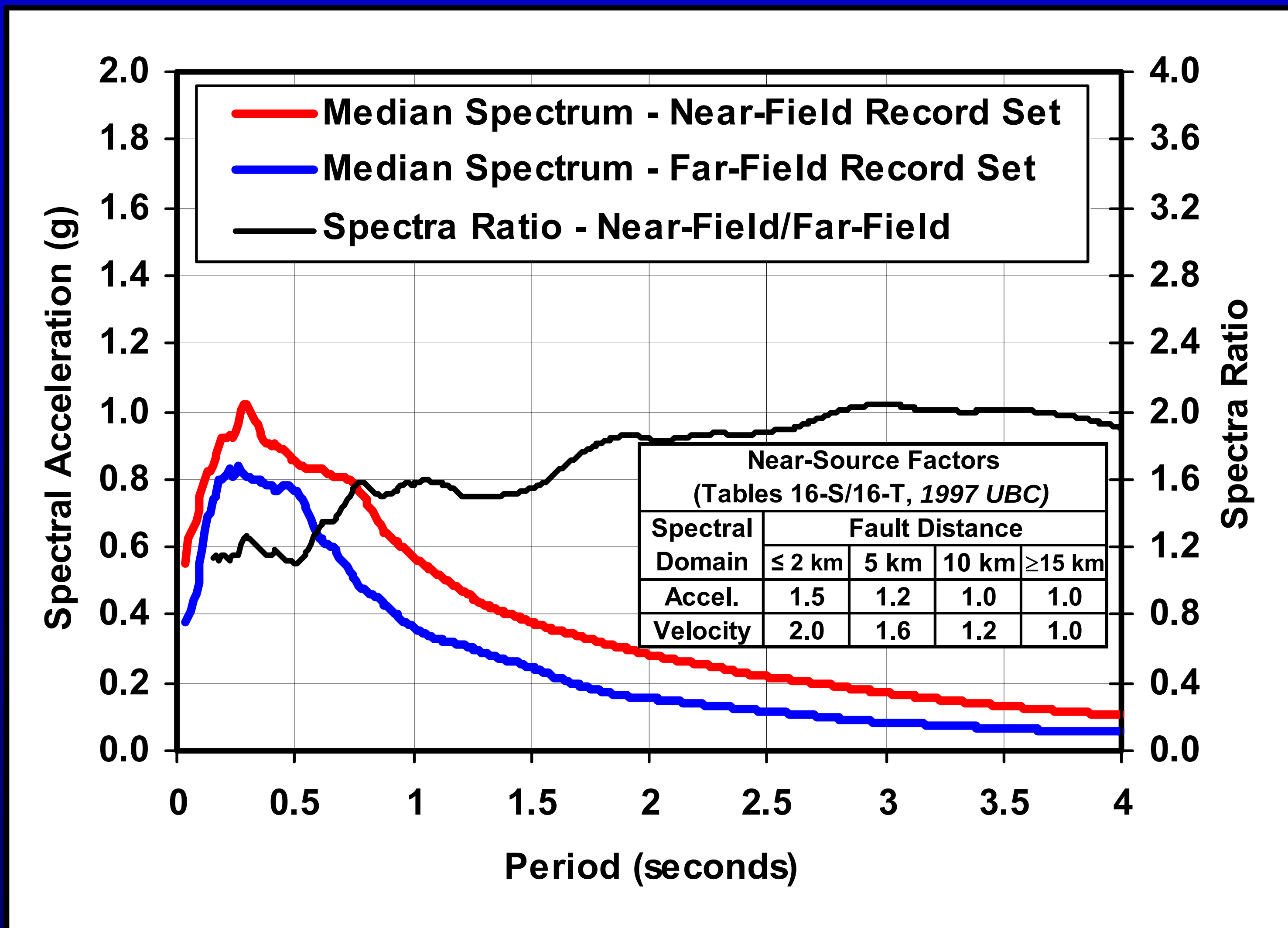
Pulse Records – Distribution by Magnitude, Distance and Direction



Response Spectra – Near-Field Record Set



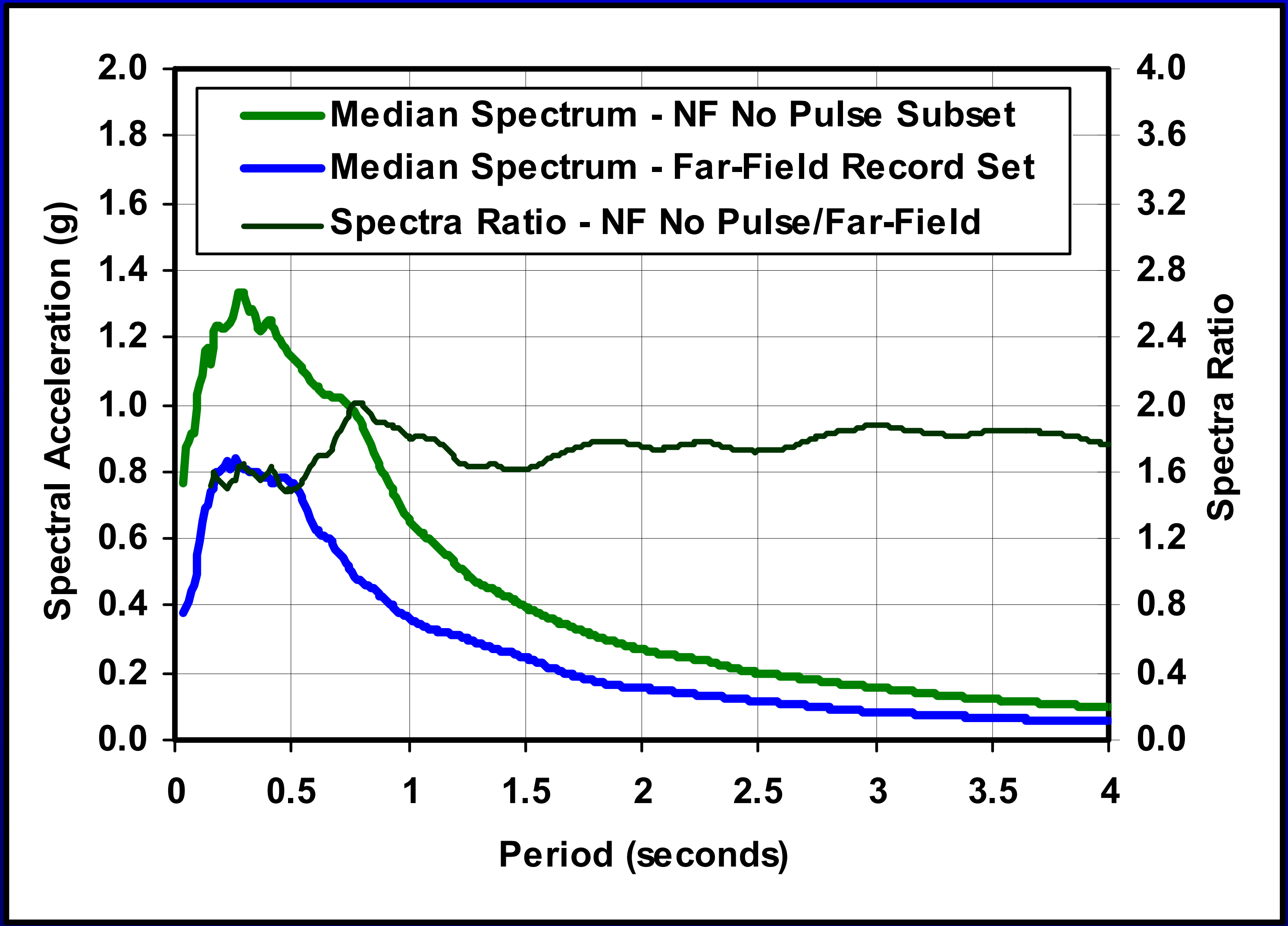
Comparison of Median Spectra – Far-Field and Near-Field Record Sets



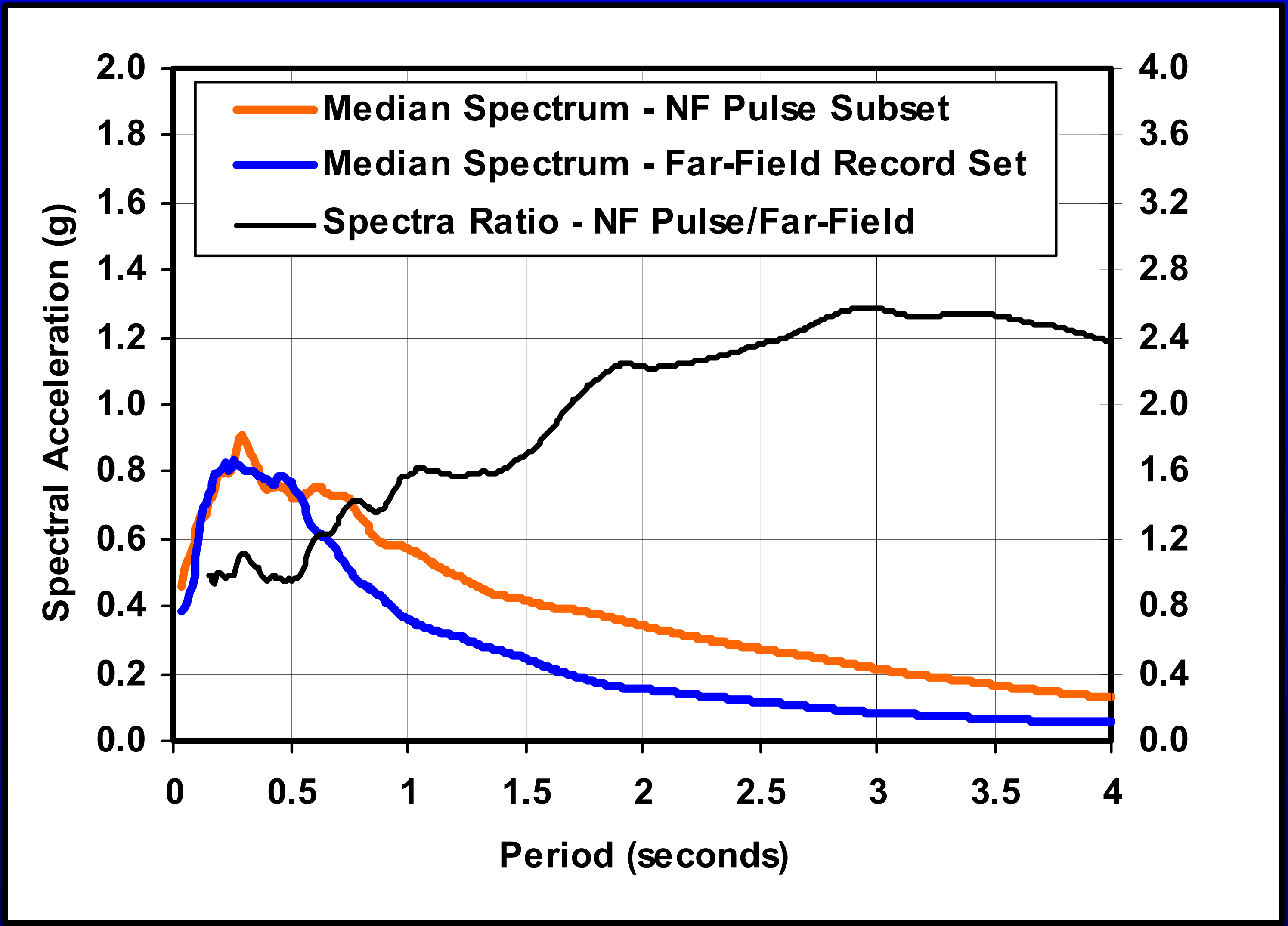
Near-Source Factors (Tables 16-S/16-T, *1997 UBC)*

Spectral Domain	Fault Distance			
	≤ 2 km	5 km	10 km	≥15 km
Accel.	1.5	1.2	1.0	1.0
Velocity	2.0	1.6	1.2	1.0

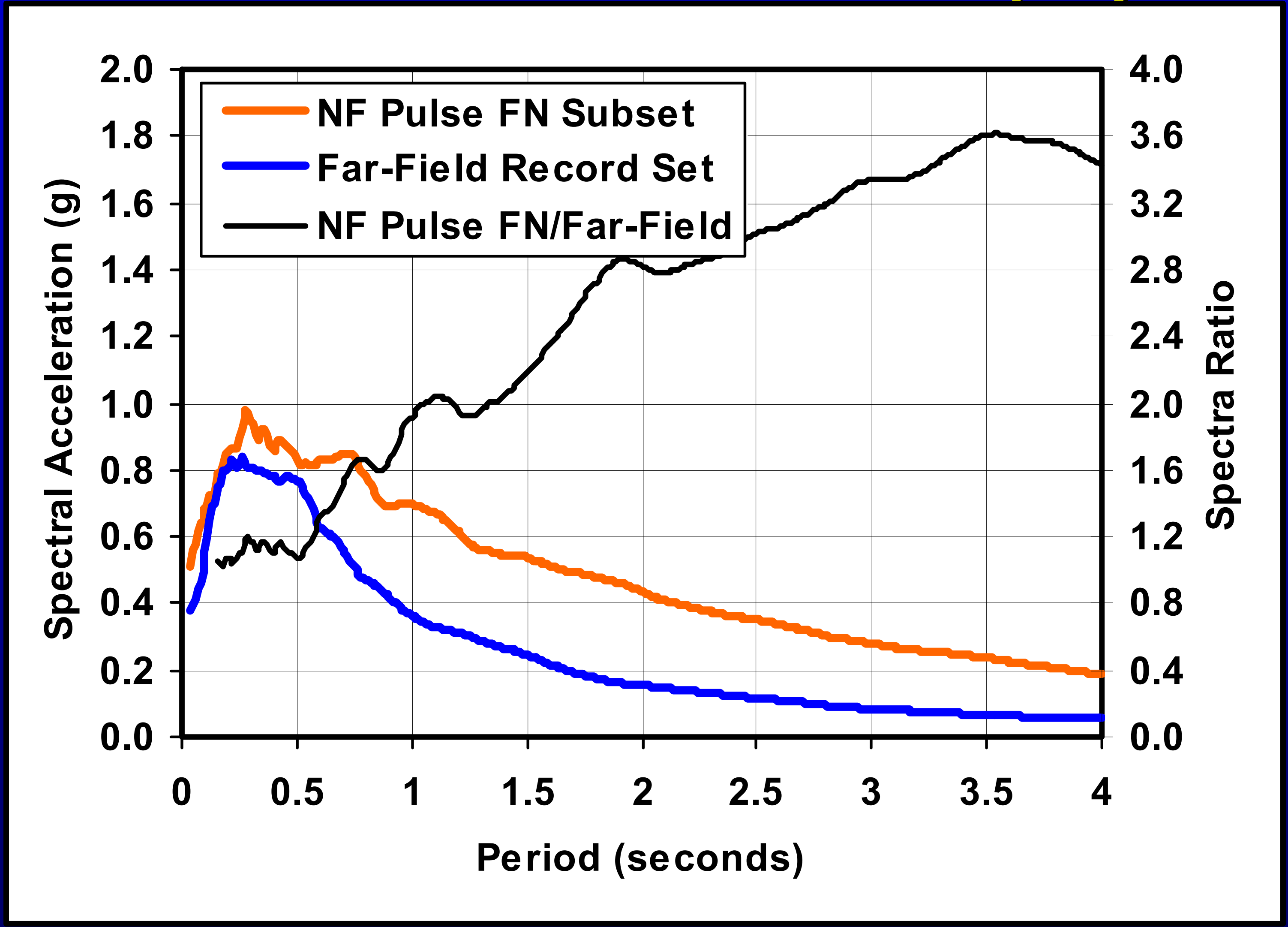
Comparison of Median Spectra – Far-Field Set and Near-Field *No Pulse Subset*



Comparison of Median Spectra – Far-Field Set and Near-Field *Pulse Subset*



Comparison of Median Spectra – Far-Field Set and Near-Field *Pulse-Fault Normal (FN) Subset*



Example Comparison of Collapse Results
Far-Field and Near-Field Record Sets

4-Story RC SMF (Space Frame)			Spectral Shape Adjustment				
Ground Motions			No Ajustment			Adjustment (ε = +1.5)	
Basic Set	Subset	Comp's.	Margin	Beta-IDA	P[C|MCE]	Margin	P[C|MCE]
Far-Field	Full Set	Both	2.5	0.41	0.08	3.6	0.03
Near-Field	Full Set	Both	2.1	0.41	0.12		
Near-Field	No Pulse	Both	2.2	0.45	0.11		
Near-Field	Pulse	Both	2.1	0.26	0.13		
Near-Field	Pulse	FN	1.8	0.38	0.16		

- Near-Field Set (Full Set) – Modest decrease in collapse margin:
  - 20% decrease for 4-Story RC SMF, but results vary for other archetypes analyzed)
  - Perspective - Spectral Shape (epsilon of +1.5) causes a 50% increase in collapse margin
- Far-Field/Near-Field Results – Similar collapse probabilities when P[C|MCE] incorporates modeling and other uncertainties.